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The World of Virtual Actors

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9.1. Introduction

The long-term objective of our research is the visualization of the simulation of the behavior of realistic human beings, called **synthetic actors**, in a given environment, interactively decided by the animator. The ultimate reason for developing realistic-looking synthetic actors is to be able to use them in virtually any scene that re-creates the real world. However, a virtual scene -- beautiful though it may be -- is not complete without people.... Virtual people, that is. Scenes involving synthetic actors imply many complex problems we have been solving for several years (Magnenat-Thalmann and Thalmann 1991).

Behavioral techniques make possible the automating of high-level control of actors such as path planning. By changing the parameters ruling this automating, it is possible to give a different personality to each actor. This behavioral approach is a major step relatively to the conventional motion control techniques. Another complex objective is modeling human facial anatomy exactly, including movements to satisfy both structural and functional aspects of simulation. In order to improve the realism of synthetic actors, there are two important features to render: hair and clothes. Realistic hair has long been an unresolved problem because the great number of geometrical primitives involved and the potential diversity of the curvature of each strand of hair make it a formidable task to manage. Dressing synthetic actors with complex clothes is also a challenge. It is somewhat difficult

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to realistically animate complex objects consisting of many surface panels like trousers or jackets without proper dynamic constraints. Problems include seaming the surface panels together, attaching them to other rigid objects, and calculating collision responses when they self-collide or collide with rigid objects.

In Section 9.2, we discuss the problem of controlling synthetic actors. It presents the development of a general concept of autonomous actors reacting to their environment and taking decisions based on perception systems, memory and reasoning. Section 9.3 explains the specific problem of facial animation and communication. In Section 9.4, we will review techniques for rendering fur and hair and modeling hairstyle. We emphasize a method based on pixel-blending for generating images completely free of aliasing artifacts. In the last section, we present methods for designing and animating clothes. Deformable models provide a powerful approach to this problem.

9.2. Animation System with Autonomous Actors

Most of the computer-generated films have been produced using traditional computer animation techniques like keyframe animation, spline interpolation, etc. Automatic motion control techniques (Wilhelms 1987) have been proposed, but they are strongly related to mechanics-based animation and do not take into account the behavior of characters. In fact, there are two ways of considering three-dimensional computer animation (Magnenat Thalmann and Thalmann 1990) and its evolution. The first approach corresponds to an extension of traditional animation methods. The animator uses the computer to assist in the creation of keyframes and simple motions and deformations like stretching and squashing. The second approach corresponds to simulation methods based on laws of physics, physiology or even psychology. The purpose is not the same: traditional methods allow us to create three-dimensional characters with exaggerated movements while simulation methods are used to try to model a human behavior accurately. High-level animation involving human beings and animals may be produced in this way.

Many authors have proposed methods to implement motion of articulated bodies. Some methods come from robotics like inverse kinematics and dynamics. Inverse kinematics permits direct specification of end point positions (e.g., a hand or foot). There are two major problems in inverse kinematics: finding any solution that will achieve the desired goal and, finding the most desirable solution. Inverse kinematics can be used as constraints with dynamic simulations (Isaacs and Cohen 1987). Dynamics has been used to automatically generate realistic motion (Armstrong and Green 1986; Wilhelms and Barsky 1985) that successfully animates the motion of chains, waves, spacecraft, and automobiles. The problem is that force/torque control is not intuitive. The course of a simulation is completely determined by the objects' initial positions and velocities, and by forces applied to the objects along the way. It just solves the initial value problems. How to return some level of control to the animator is one of the most difficult issues in dynamic simulation.

In task-level animation (Badler et al. 1989; Zeltzer 1989), the animator specifies what the synthetic actor has to do, for instance, "jump from here to there". For example, Witkin and Kass (1988) describe a spacetime constraint system in which constraints and objectives are defined over spacetime, referring to the set of all forces and positions of all of a creature's degrees of freedom from the beginning to the end of an animation sequence. Cohen (1992) takes this concept further and uses spacetime windows to control the animation interactively. But, task-level animation raises a problem: how to introduce individual differences into the generic activities which are generated automatically ? In the task of walking, everybody walks more or less the same way, following more or less the same laws. It is the "more or less" which is difficult to model. Even the same person does not walk the same way everyday. If he is tired, or happy, or has just received some good news, the way of walking will appear somewhat different. As in traditional animation, an animator can create a lot of keyframes to simulate a tired character walking, but this is a very costly and time-consuming task.

To individualize human walking, we have developed (Boulic et al. 1990) a model built from experimental data based on a wide range of normalized velocities (see Figure 9.1). The model is structured on two levels. At a first level, global spatial and temporal characteristics (normalized length and step duration) are generated. At the second level, a set of parameterized trajectories produce both the position of the body in space and the internal body configuration, in particular the pelvis and the legs. This is performed for a standard structure and an average configuration of the human body. The experimental context corresponding to the model is extended by allowing continuous variation of the global spatial and temporal parameters for altering the motion to try to achieve the effect desired by the animator. The model is based on a simple kinematics approach designed to preserve the intrinsic dynamic characteristics of the experimental model. But what is important is that this approach allows individualization of the walking action in an interactive real-time context in most cases.

Figure 9.1. Biomechanics walking

Virtual humans are not only visual. They have a behavior, perception, memory and some reasoning. Behavior is often defined as the way animals and humans act, and is usually described in natural language terms which have social, psychological or physiological significance, but which are not necessarily easily reducible to the movement of one or two muscles, joints or end effectors. In fact the behavior of any living creature may be simulated. Reynolds (1987) introduced the term and the concept of behavioral animation in order to describe the automating of such higher-level animation. Behavior is not only reacting to the environment but should also include the flow of information by which the environment acts on the living creature as well as the ways the creature codes and uses this information. Reynolds studied in detail the problem of group trajectories: bird flocks, herds of land animals and fish schools.

A typical human behavioral animation system is based on the three key components:

- the locomotor system
- the perceptual system
- the organism system

A locomotor system is concerned with how to animate physical motions of one or more actors in their environment. This is the control part of the system. A perceptual system is concerned with perceiving the environment. According to Gibson (1966), we may consider five perceptual systems: basic orienting system, auditory system, haptic system, taste-smell system, and visual system. The organism system is concerned with rules, skills, motives, drives and memory. It may be regarded as the brain of the actor.

Our main purpose is the development of a general concept of autonomous actors reacting to their environment and taking decisions based on perception systems, memory and reasoning. With such an approach, we should be able to create simulations of situations such as actors moving in a complex environment they may know and recognize, or actors playing ball games based on their visual and touching perception.

Although many techniques have been developed for the control of articulated bodies, they are generally applied to much simpler systems than humans. For a general **locomotor system**, only a combination of various techniques may result in a realistic motion with a relative efficiency. Consequently, our locomotor system is based on several integrated methods. As we have already developed several techniques: keyframe, inverse kinematics, direct/inverse dynamics (Figure 9.2) and biomechanics-based walking, we integrate them using a blending approach. Production of a natural looking motion based on the integration of all parts of body using different types of motion control methods is certainly a challenge. In our case, a blending module is associated with the coach-trainee correction method that we have created in the context of walking. This method allows the kinematics correction of joint-space based motion with respect to Cartesian constraints (Boulic and Thalmann 1992). In such a way, it is still possible to modify the keyframe sequence, a low-level description of motion, for a higher level goal-oriented requirement. We believe that this approach will greatly extend the scope of predefined motions (rotoscopy, specialized model, keyframed etc..). A new methodology emerges for motion conception and editing which is centered on the coach-trainee correction method. The functional diagram in Figure 9.3 organizes the composition of the input motions around the blending module prior to the coach-trainee correction module.

Figure 9.2. Dynamics-based motion

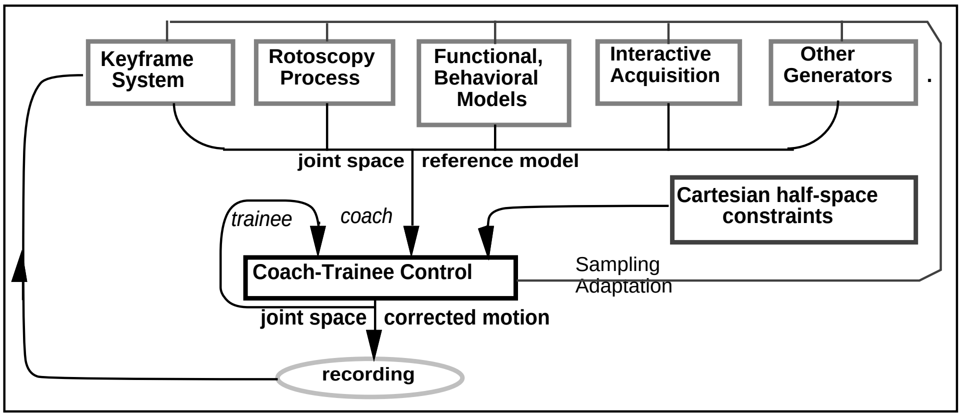

Figure 9.3. Functional diagram of motion blending

A **perceptual system** is concerned with perceiving the environment. The most important perceptual subsystem is the vision system. The originality of our approach in this wide research area is the use of a synthetic vision as a main information channel between the environment and the actor (Renault et al. 1990). We model the actor brain with a memory (essentially visual) and a limited reasoning system allowing the actor to decide his motion based on information. The movement decision procedure is the central coordinator to determine further movement. Our approach is based on the use of Displacement Local Automata (DLA), which is similar to the concept of script introduced by Schank (1980) for natural language processing. For vision, a DLA is a black box which has the knowledge allowing the synthetic actor to move in a specific part of his environment. Examples are the DLA *displacement-in-a-corridor*, the DLA *obstacle-avoidance*, the DLA *crossing-with-another-synthetic-actor* , the DLA *passage-of-a-door* etc. This concept of DLA has the advantage of being able to increase or decrease the description level. The DLA system allows for the creation of a kind of assemblage game where, using simple and modular elements, it is possible to react to a lot of everyday simple situations. It should be noted that our DLAs are strictly algorithmic; they correspond to reflexes which are automatically performed by the adult and they only use vision as the information source.

The controller is the thinking part of our system or the **organism system**. It makes decisions and performs the high-level actions. In an unknown environment, it analyzes this environment and activates the right DLA. In the simpler case of a known environment (i.e. already used), the controller directly activates the DLA associated with the current location during the learning phase. This controller also has to handle the DLA end, the DLA errors and other messages coming from the DLAs. In particular, a DLA may be in a situation where it does not know what to do and the controller should solve the problem. In any known environment, the controller should be able to activate the DLA associated with the current location. This means that an environment description has to be stored somewhere. This is the role of the navigator. From information provided by the controller (information that can come itself from DLAs), the navigator builds step by step a "map" of the environment. The navigator then gives to the controller the location of the synthetic actor in the map, and of course, it should plan the path from a known location to another known location (at a high level: e.g. go to the kitchen). Another function of the navigator is to allow the controller to change the initialization of some DLAs (e.g. changing the attention level in the corridor) and anticipate the DLA changes. This description of the navigator functionalities emphasizes the role of the map which should be more a logical map than a geographical map, more a discrete map than a continuous map. In fact, human beings only remember discrete properties like *the tree is on the right of the car*. This suggests that to give to the behavior of the synthetic actor a maximum of believability and a maximum of developing possibilities, it is essential to give the actor a world representation similar to the representation that human beings have.

More complex problems come when the actor is supposed to know the environment, which means the introduction of an actor memory. Using his vision, the actor sees objects and stores them into his memory. Thereafter, the actor may use this memory for a reasoning process. Our actor visual memory is defined using an octree, which has to represent the visual memory of an actor in a 3D environment with static and dynamic objects. Objects in this environment can grow, shrink, move or disappear. A recursive algorithm allows a path to be found from the actor to any position avoiding the obstacles based on his memory. The actor should also be able to remember if there is no path at all or if there are loops as in a labyrinth. This requires implementation of a backtracking mechanism. Once an actor has found a good path, he may use his memory/reasoning to take the same path. However, as new obstacles could have been added on the way, the actor will use the current synthetic vision to decide the exact path, reacting to the new obstacles. Figure 9.4 (see Color Section) shows an example of vision-based animation.

9.3. Face, Skin, Hair and Beards

Computer modeling and animation of synthetic faces has attained a considerable attention recently. Because the human face plays the most important role for identification and communication, realistic construction and animation of the face are of immense interest in the research of human animation. The ultimate goal of this research would be to model exactly the human facial anatomy and movements to satisfy both structural and functional aspects. However, this involves many problems to be solved concurrently. The human face is a very irregular structure, which varies from person to person. The problem is further compounded with its interior details such as muscles, bones and tissues, and the motion which involves complex interactions and deformations of different facial features.

For our facial deformations, we have extended the concept of Free Form Deformations (FFD) introduced by Sederberg and Parry (1986), a technique for deforming solid geometric models in a free-form manner (Kalra et al. 1992). More details may be found in Chapter 14.

To improve the "Barbie-like" aspect of virtual humans, we propose a technique based on texture mapping of photos of real faces (Kalra and Magnenat Thalmann 1993). A separate tool for matching the 3D facial topology on a given picture/photo of a face is developed. Only a few feature points are selected from the 3D model to exactly match the corresponding points on the picture. Delaunay triangulation is used to connect these points. These points can be moved and displaced on the picture interactively. An interpolation scheme in a triangular domain is used to get the desired texture coordinates. As a result the picture is deformed and mapped on the 3D model. In order to map the entire head, multiple views are needed. These pictures are projected on a cylinder. Then the corresponding matching is performed between the cylindrical projected 3D model points and cylindrical projected pictures. By using texture mapping the quality of rendering improves considerably. In addition, it allows us to put a picture of a specific person on a given 3D model.

In the field of human animation, hair presents perhaps the most challenging rendering problem and therefore has been one of the least satisfactory aspects of human images rendered to date. The difficulties of rendering hair result from the large number and detailed geometry of the individual hairs, the complex interaction of light and shadow among the hairs, and the small scale of the hair width in comparison with the rendered image. The rendering of hair therefore constitutes a considerable anti-aliasing problem in which many individual hairs, reflecting light and casting shadows on each other, contribute to the shading of each pixel.

Several researchers have published methods for rendering fur and human hair. Gavin Miller (1988) modeled hair with triangles to form a pyramid, using oversampling to avoid aliasing. Watanabe and Suenaga (1989) modeled human hairs as connected segments of triangular prisms and were able to render a full head of straight human hair in a reasonably short time using a hardware Z-buffer renderer with Gouraud shading. Perlin and Hoffert (1989) employed volume densities, controlled with pseudo-random functions, to generate soft furlike objects. Perhaps the most impressive rendering of fur to date was achieved by Kajiya and Kay (1989) for a teddy bear using a generalization of 3D texturing known as texels. Rosenblum et al. (1991) presented hair animation methods using a mass spring model. Anjyo et al. (1992) proposed methods using one-dimensional projective differential equations and pseudo-force fields. Both methods neglect the effect of collision between hairs for simplicity. Kurihara et al. (1993) proposed a simplified collision detection method using cylindrical representation.

To create hairstyles, our program offers, in the special module HairStyler, some interactive facilities. First, the three-dimensional curved cylinder is composed of straight cylindrical segments connected by points. The "in-between" points can be moved in the space to be adjusted, modified, deleted, or added. Just one type of individual hair can be assigned to each triangle in the scalp mesh. However the same hair can be assigned to various triangles. In order to adjust the hair orientation on the curved scalp surface, its direction can be modified by rotating the hair around the normal of its triangle. After defining each hair format and applying it to the respective triangle, the final style can be defined. The same hairstyle can have different lengths, by making it grow or shrink using a multiplication factor. A hairstyle generally has between 100,000 and 150,000 hairs, but this density can be regulated either for individual triangles or the entire scalp. Initially all the hairs placed in the triangle have the same length, orientation and symmetrical position. To make hairstyles look more natural, all these parameters can be changed interactively. A random length, orientation and position can be assigned to each triangle hair set.

Rendering an image of hair with our system involves several steps:

- creating a database of hair segments
- creating shadow buffers from all lights

- rendering the hairless objects using all shadow buffers
- composing the hair on the hairless image

In our system, hair rendering is done by raytracing using a modified version of the public domain Rayshade program. An implementation module of the shadow buffer algorithm (Williams 1978) has been added to a raytracing program, based on an earlier version of hair rendering based on pixel blending (Leblanc et al. 1991). The process is step by step. First, the shadow of the scene is calculated for each light source, as well as for the light sources for the hair shadows. The hair shadows are calculated for the object surface and individually for each hair. Finally the hairstyle is blended into the scene, using all shadow buffers. The result is an image with a three-dimensional realistic hairstyle rendering where complex shadow interaction and highlight effects can be seen and appreciated. Figure 9.5 shows an example of a synthetic actress with a hairstyle. Figure 9.6 (see Color Section) shows an example of a synthetic actor with hair, beard and skin texture.

Figure 9.5. Synthetic actress with hairstyle

9.4. Clothes

Cloth animation in the context of human animation involves the modeling of garments on the human body and their animation. In our film "Rendez-vous à Montréal" (Magnenat Thalmann and Thalmann 1987) featuring Humphrey Bogart and Marilyn Monroe, clothes were simulated as a part of the body with no autonomous motion (see Figure 9.7). For modeling more realistic clothes, two separate problems have to be solved: cloth animation without considering collisions (only the basic shape and the deformations due to gravity and wind are considered), and collision detection of the cloth with the body and with itself.

Figure 9.7. Cloth designed as a simple color (from the film "Rendez-vous à Montréal")

In a geometric approach, the shape of flexible objects is entirely described by mathematical functions. It is not very realistic and cannot create complicated deformable clothes, but it is fast. The geometric approach is suitable for representing single pieces of the objects or clothes with simple shapes, which are easily computed, but geometric flexible models like Weil's model (Weil 1986) or Hinds and McCartney's model (Hinds and McCartney 1990) have not incorporated concepts of quantities varying with time, and are weak in representing physical properties of cloth such as elasticity, anisotropy, and viscoelasticity. Only physical models like Terzopoulos' model (Terzopoulos et al. 1987) and Aono's model (Aono 1990) may correctly simulate these properties. Another interesting approach by Kunii and Gotoda (1990) incorporates both the kinetic and geometric properties for generating garment wrinkles.

In our approach, we work as a tailor does, designing garments from individual two-dimensional panels seamed together. The resulting garments are worn by and attached to the synthetic actors. When the actors are moving or walking in a physical environment, cloth animation is performed with the internal elastic force and the external forces of gravity, wind, and collision response.

Our work in cloth animation (Carignan et al. 1992) is based on the fundamental equation of motion as described by Terzopoulos et al. (1987) with the damping term replaced by a more accurate one proposed by Platt and Barr (1989). When a collision is detected, we pass through the second step where we act on the vertices to actually avoid the collision. For this collision response, we have proposed the use of the law of conservation of momentum for perfectly inelastic bodies. This means that kinetic energy is dissipated, avoiding the bouncing effect. We use a dynamic inverse procedure to simulate a perfectly inelastic collision. Such collisions between two particles are characterized by the fact that their speed after they collide equals the speed of their centers of mass before they collide.

The constraints that join different panels together and attach them to other objects are very important in our case. Two kinds of dynamic constraints (Barzel and Barr 1988) are used during two different stages. When the deformable panels are separated, forces are applied to the elements in the panels to join them according to the seaming information. The same method is used to attach the elements of deformable objects to other rigid objects. When panels are seamed or attached, a second kind of constraint is applied which keeps a panel's sides together or fixed on objects. Figures 9.8, 9.9 (see Color Section) and 9.10 (see Color Section) show examples of a dressed synthetic actress. Figure 9.11 (Color Section) shows an example of walking sequence with clothes. Figure 9.12 (see Color Section) shows an example with hair, fur and skin texture.

Figure 9.8. Dressed synthetic actress

9.5. Conclusion

Modeling humans using computers is a very complex task. It will take years before we are able to represent synthetic actors who look and behave realistically. And if these actors are not to behave all in the same way, we will have to introduce interactive psychological description capabilities. New problems will arise: how to model the personality, the know-how, the common sense, the mind? We need concrete and mathematical models of domains which as yet are far from being formally described. This may be the challenge for the computer modeling of humans in the coming century.

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